Energy research Centre of the Netherlands

Transition to the hydrogen economy

Marcel Weeda, *Energy research Centre of the Netherlands (ECN)*

AERO-NET Workshop, Sheffield, 25 January 2007

Energy Research Centre of the Netherlands (ECN)

- Independent research organisation;
- Bridge between fundamental research and industrial products;
- 550-600 employees;
- Annual turnover 65 M€

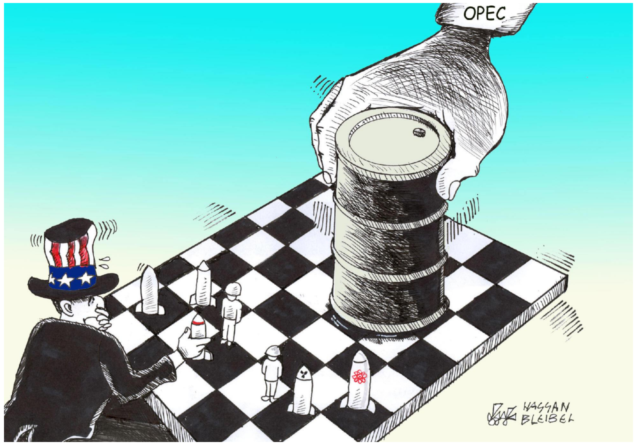
- **Unit:**
  Hydrogen and
  Clean Fossil Fuels
- **Group:**
  Hydrogen Transitions and Infrastructure

Structure presentation

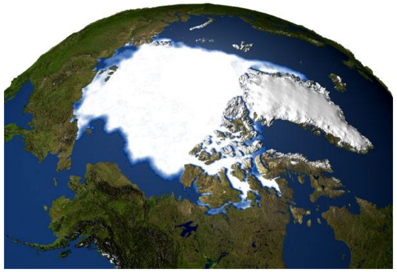
- Energy issues
- Role of hydrogen and applications
- General views on hydrogen transition
- Source to user
  - Primary energy use
  - GHG-emissions
  - Fuel cost
- Vehicle cost
- On-board and on-site storage
- Status and activities
- Summary/Conclusions

Issues w.r.t. supply and use of energy

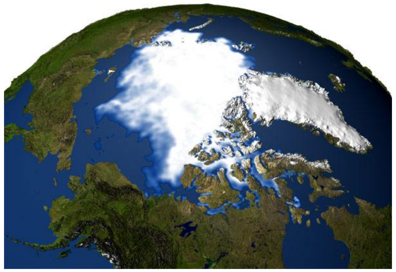
- Availability and undesirable dependencies



- Climate change



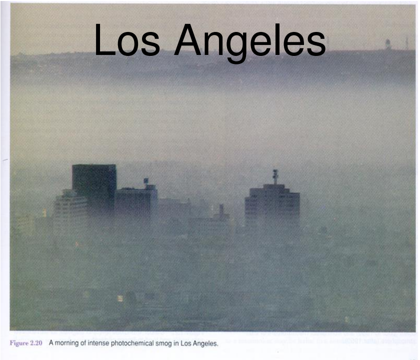
Arctic sea ice, 1979

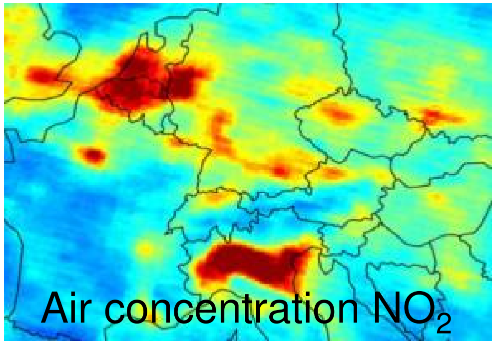


Arctic sea ice, 2003

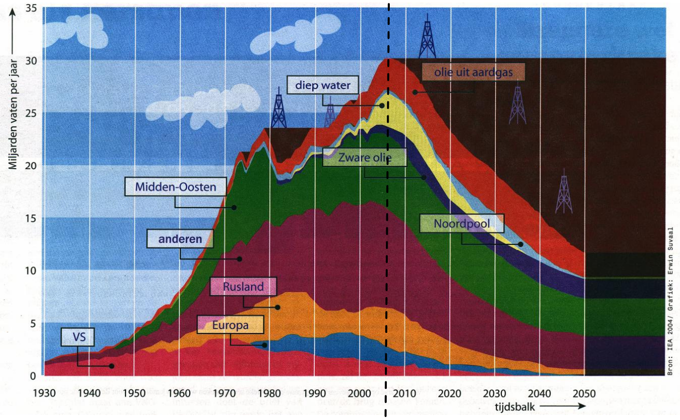
Issues w.r.t. supply and use of energy

- Air pollution



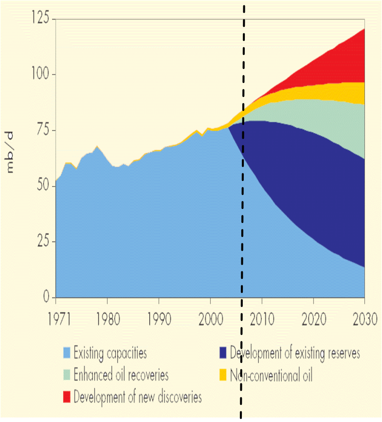


- Fossil resources are finite, in particular oil and natural gas



ASPO:
we have reached
the oil peak

IEA:
there is enough



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Hydrogen is part of the solution

General options:

- Conservation; avoid the use of energy
- Increase energy conversion efficiency (transformation, end-use)
- Use of clean energy sources and energy carriers
- Use of climate neutral energy sources and energy carriers
- Use of energy carriers that can be produced from various energy sources

Specific options:

- Hydrogen: clean, carbon-free, universal (like electricity)
- Fuel Cells: efficient conversion of hydrogen into electricity

Applications for hydrogen and fuel cells (1)

- Transport
  - Propulsion:
    - moped, scooter, motor
    - passenger car
    - van
    - light duty truck
    - bus
  - Auxillary Power Unit:
    - heavy duty truck
    - airplane
    - ship




100-500 kW
Hydrogen from kerosine

10-10,000 kW
Hydrogen from marine diesel

Applications for hydrogen and fuel cells (2)

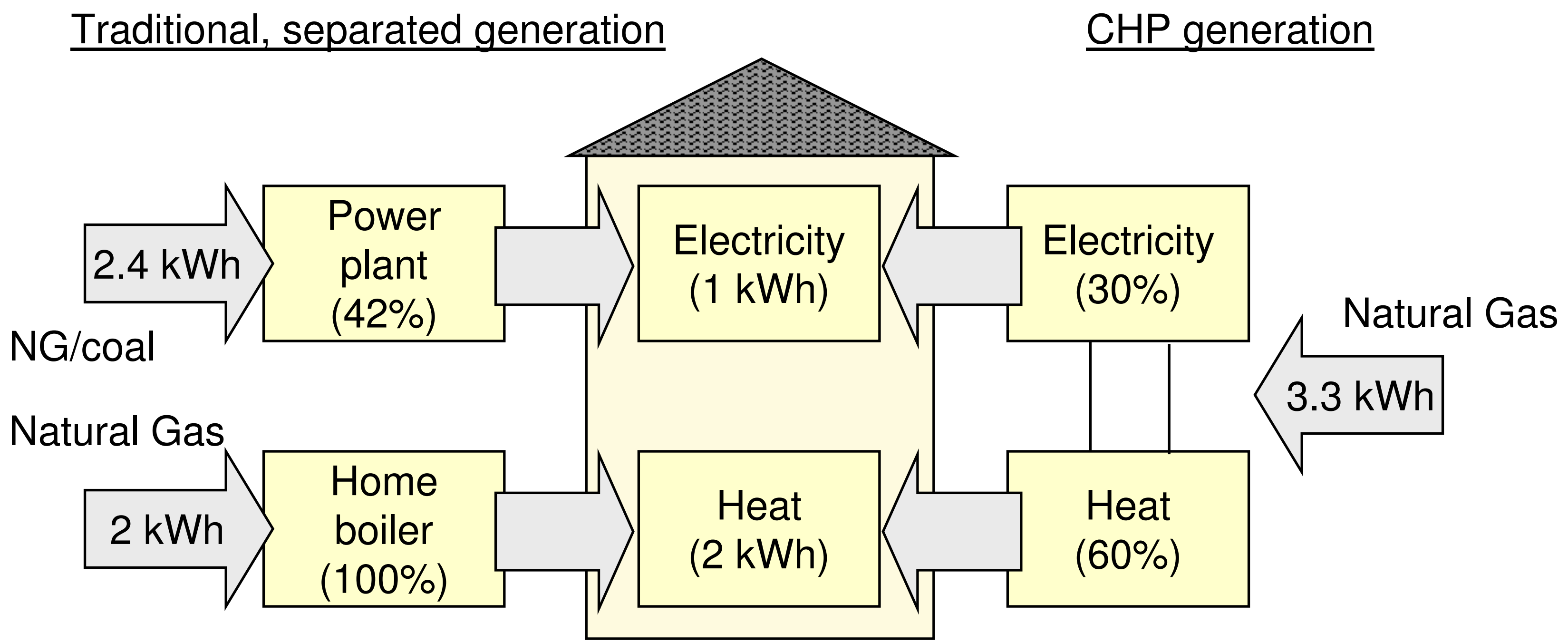
- Residential and commercial sector, and agriculture
  - Back-up power, or Uninterrupted Power Supply (UPS)
  - Portable power and mobile power (power generators)
  - Energy storage (e.g. wind, solar) in remote areas
  - Mini- and micro-CHP ?

Potential mini- and micro-CHP is not clear. Savings depend on:

- Heat to power ratio
- Load curves (simultaneity in heat and power demand)
- Temperature level of the heating system
- Capacity of the system
- Control strategy of the system
- Characteristics reference system

Furthermore, many alternatives available, like better isolation, greening of electricity mix **(sustainable electricity should be used directly)**, use of solar heat, heat pumps, etc.

Energy saving by CHP: NG fuelled, optimal case

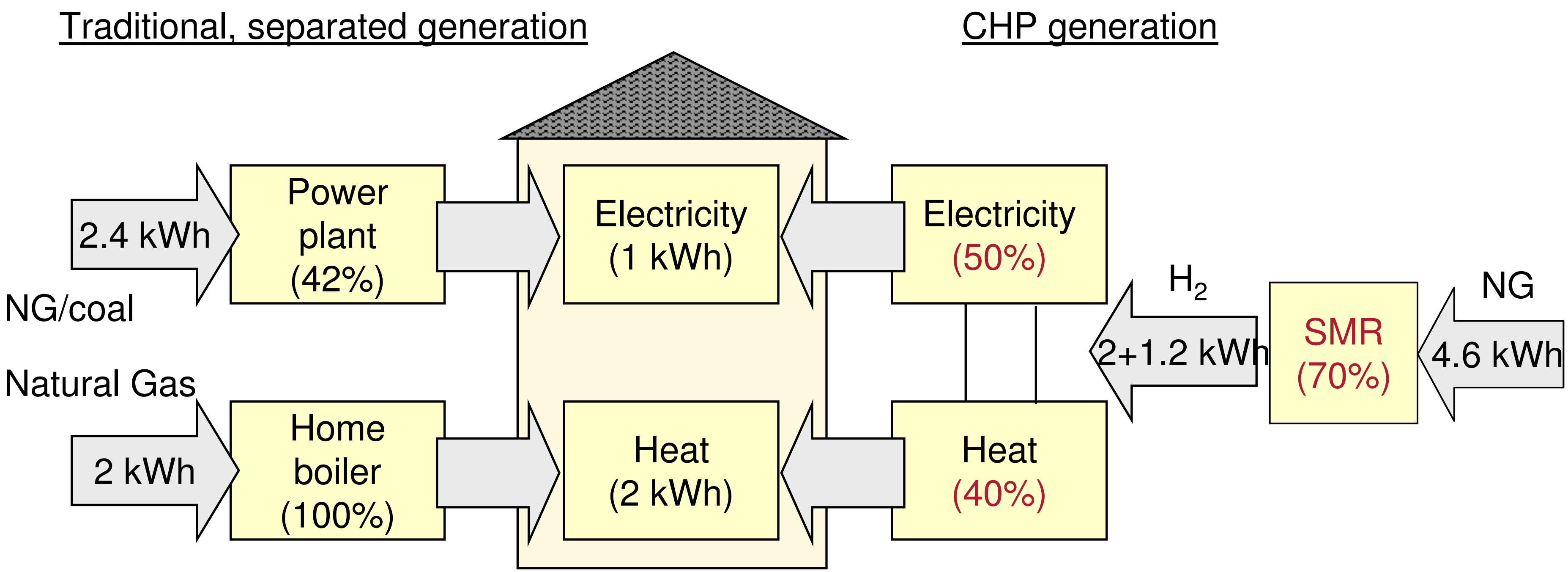


Sum: 4.4 kWh

Sum: 3.3 kWh

$$\text{energy savings} = \frac{(4.4 - 3.3)}{4.4} x100\% = 24\%$$

Energy saving by CHP: Hydrogen fuelled



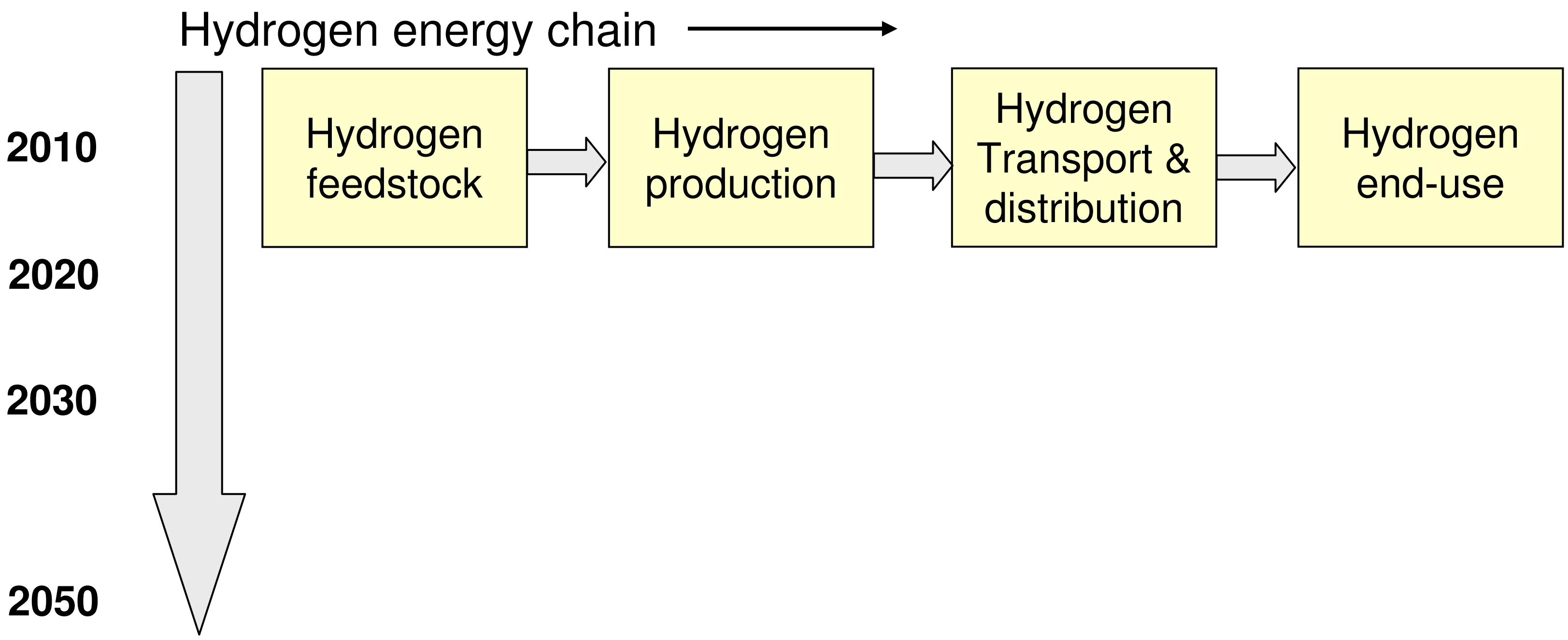
Sum: 4.4 kWh

Sum: 4.6 kWh

$$\text{energy savings} = \frac{(4.4 - 4.6)}{4.4} x100\% = -5\%$$

Transition to the hydrogen economy

- Hydrogen economy will probably be a transport fuel economy
- Transition to the use of hydrogen as an energy carrier, instead of liquid carbon-containing energy carriers, for transport applications



Transition of hydrogen transport applications

2010

- Range extension for electric vehicles (forklifts and small utility vehicles at airports, hospitals, municipal services, etc.)
- Demonstrations with busses and passenger cars (ICE & FC)
- Increase of vehicle fleets on hydrogen (e.g. busses)

2020

- FC passenger cars commercially available for private use

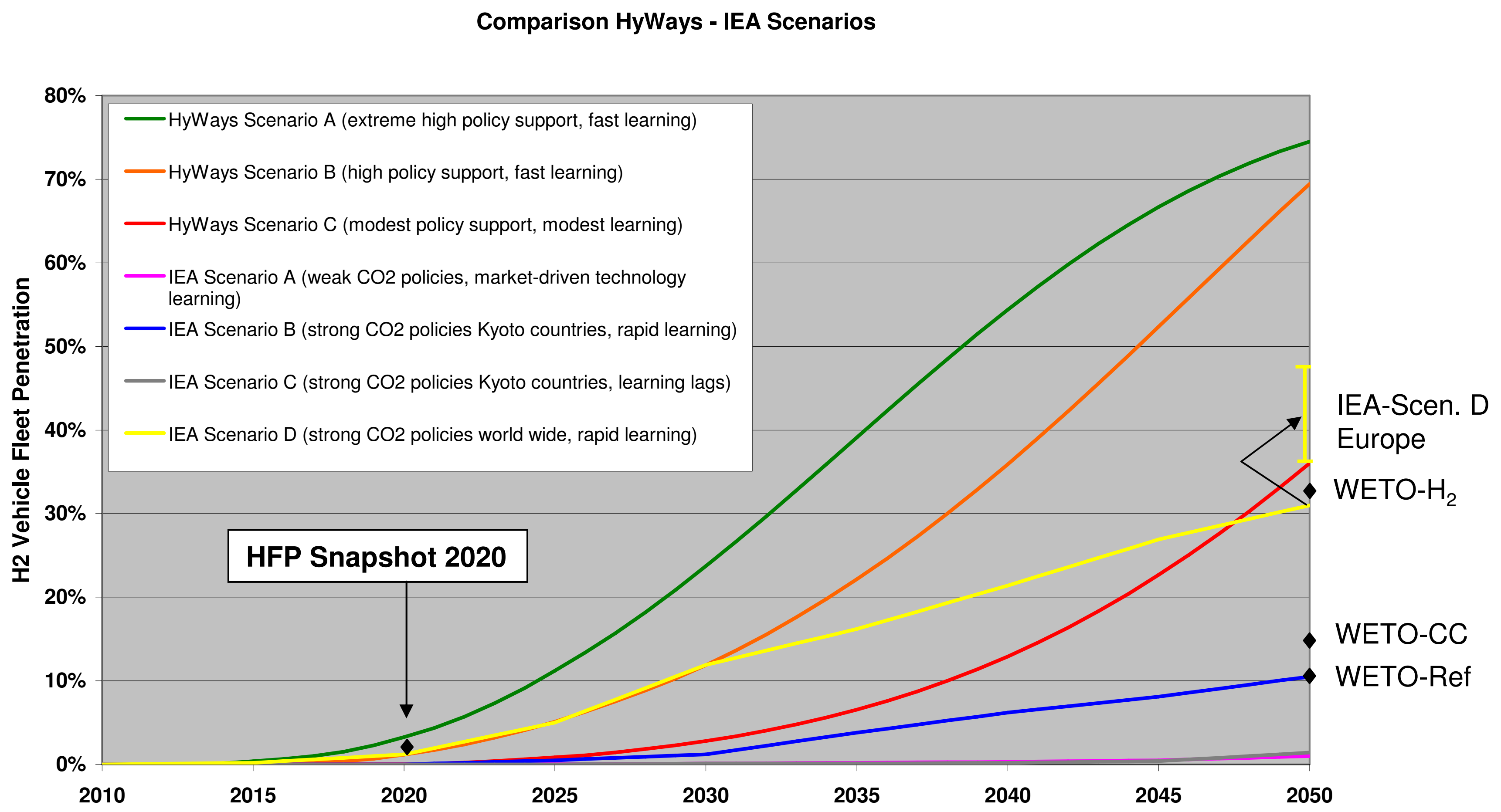
2030

- Rapid uptake of hydrogen cars in the market

2050

- Up to 50% of road transport on hydrogen

Scenarios for penetration of hydrogen vehicles



Industry plans for hydrogen vehicles

Fuel Cell Vehicle Manufacturers' Current Timetable for Launch

Manufacturer	Year	Numbers	Notes
DaimlerChrysler (Germany)	2012 2015	10,000	Initial launch, Mass Market
Ford (USA)	2015		"commercial readiness"
GM (USA)	2010-2015 2025		Commercial viability Mass Market
Honda (Japan)	2010 2020	12,000 (in USA) 50,000 (in USA)	Start production
Hyundai (Korea)	2010		Road tests 2009
Toyota (Japan)	2015		Will cost US$50,000

Fuel Cell Today, 2006 worldwide survey

An example ..., but many more available

Honda FCX

Compared to previous FCX:

- FC Stack size: -20%
- FC Stack weight: -30%
- FC Stack output: +14 kW
- Electric motor output: +15 kW
- Travel range: +30%
- Energy efficiency: +10% (abs. 60%)

Specifications:

Number of passengers		4
Motor	Max. Output	95kW (129PS, 127 horsepower)
	Max. Torque	256N-m (26.1kg-m, 188.8 lb-ft.)
	Type	AC synchronous motor (Honda Mfg.)
Fuel Cell Stack	Type	PEFC (proton exchange membrane fuel cell, Honda Mfg.)
	Output	100kW
Fuel	Type	Compressed hydrogen
	Storage	High-pressure hydrogen tank (350atm)
	Tank Capacity	171 liters (4.4 kg hydrogen)
Dimensions (L x W x H)		4,760 x 1,865 x 1,445mm (187.4 x 73.4 x 56.9 inches)
Max. Speed		160km/h (100 mph)
Energy Storage		Lithium Ion Battery
Vehicle Range*		270 miles (> 400 km)

* Preliminary EPA driving range determined by Honda using the current EPA calculation method. Source: Honda Motor Co., Ltd.

Where does the hydrogen come from?

Natural gas

Coal

Nuclear energy

Biomass

Wind energy

Geothermal heat

Solar energy

Transition of H_2 feedstocks and production

2010

2030

2050

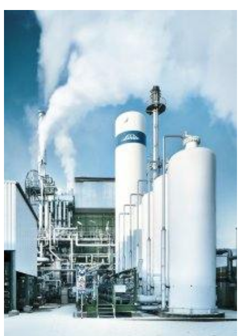
- By-product and excess capacity natural gas (NG) reformers
- On-site production via water electrolysis and NG reforming
- Clean fossil hydrogen - natural gas reforming and coal gasification including carbon capture and storage (CCS) - and nuclear hydrogen
- Renewable hydrogen from biomass (gasification) and wind (electrolysis)
- Novel technologies: thermo-chemical cycles and increasing use of solar energy (e.g. thermal water splitting and photo-electrochemical hydrogen production)

How to get the H_2 energy to the customer? (1)

as electricity

for on-site electrolysis

as natural gas for on-site SMR



liquefaction

as LH_2 by truck

How to get the H_2 energy to the customer? (2)

compression

as CGH_2

by truck

30 bar H_2 pipeline

as CGH_2

by pipeline

Transition of hydrogen transport & distribution

2010

- Available infrastructure industrial hydrogen: tube trailers and liquid hydrogen trucks
- On-site production via water electrolysis and NG reforming

2030

- Regional production with transport by liquid hydrogen trucks and tube trailers (1 LH_2 truck $\approx$ 10 tube trailers)
- Build-up of regional pipeline infrastructures
- Coupling of regional infrastructures

2050

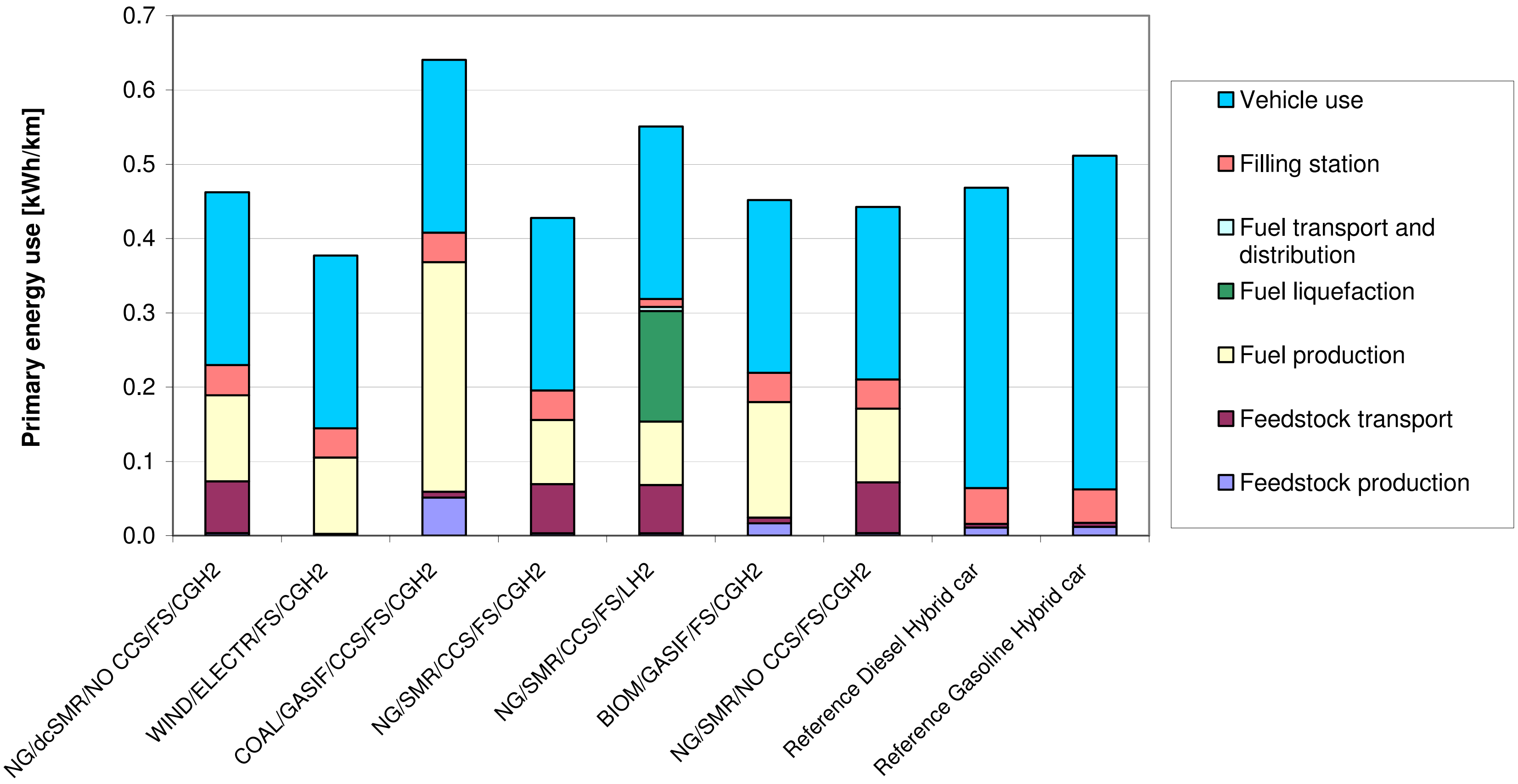
- Large hydrogen pipeline infrastructure

Maintain flexibility as long as possible

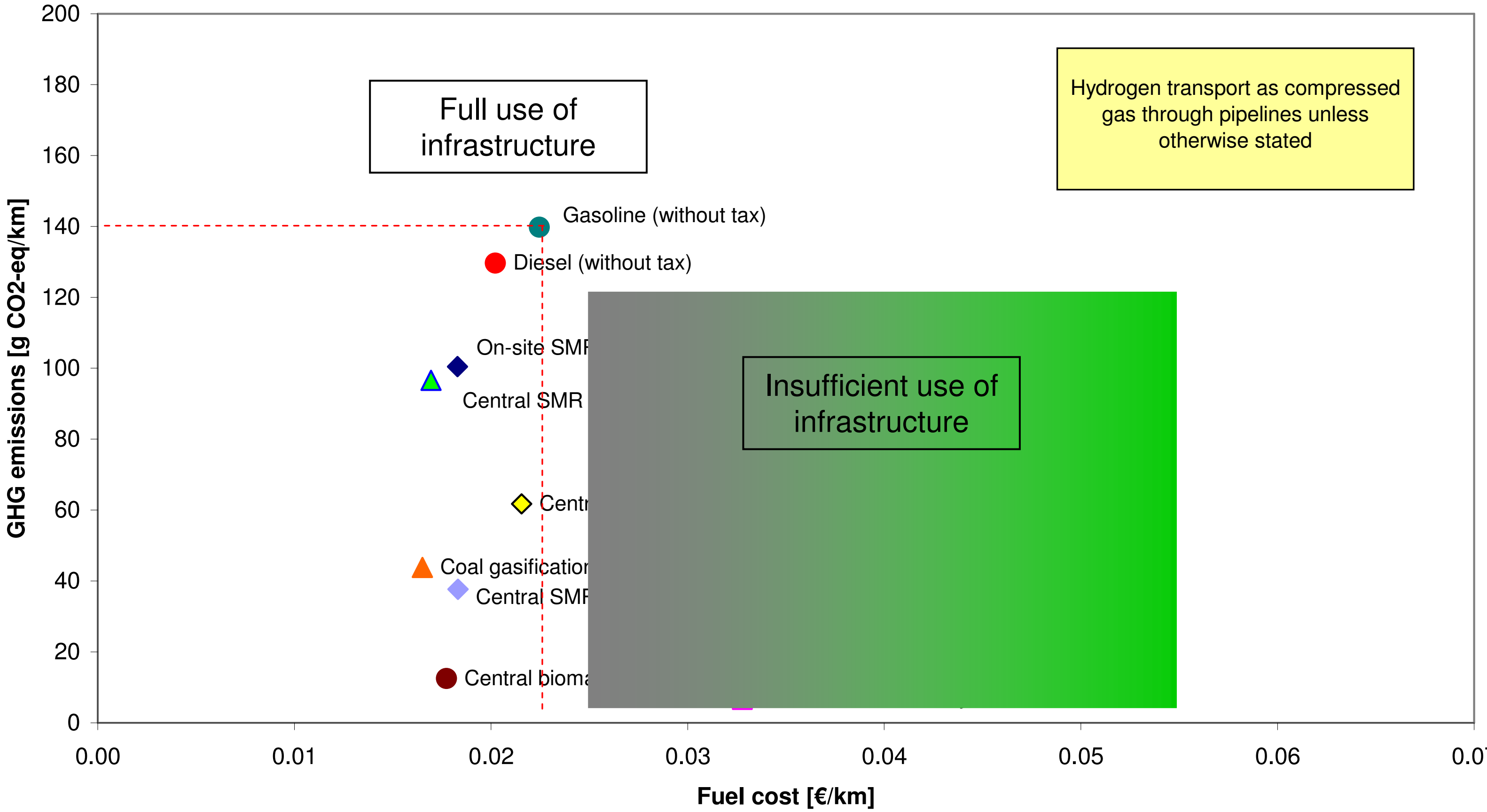
No-regret approach

Hydrogen supply in 2050

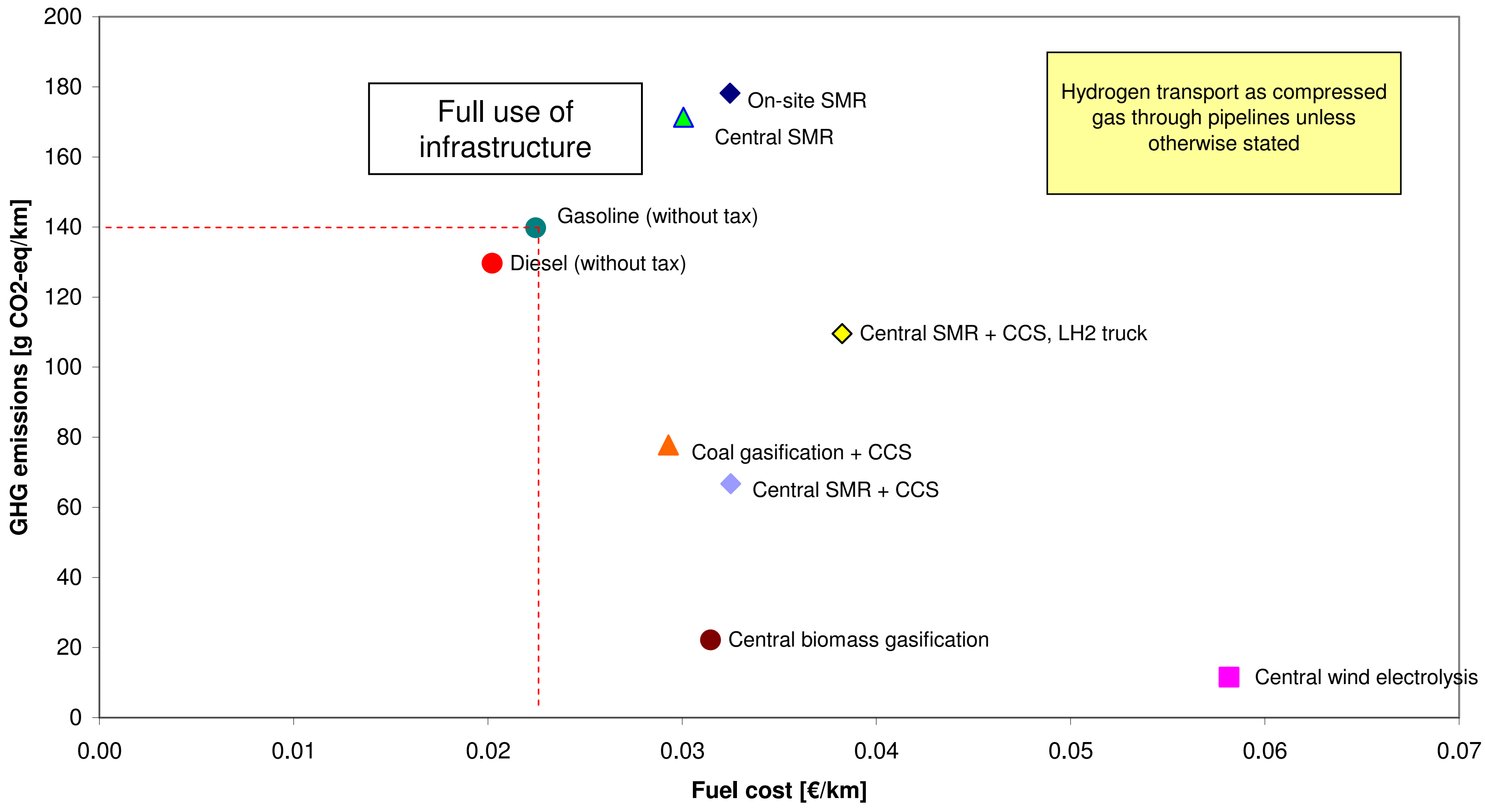
Well-to-Wheels (WTW) energy use



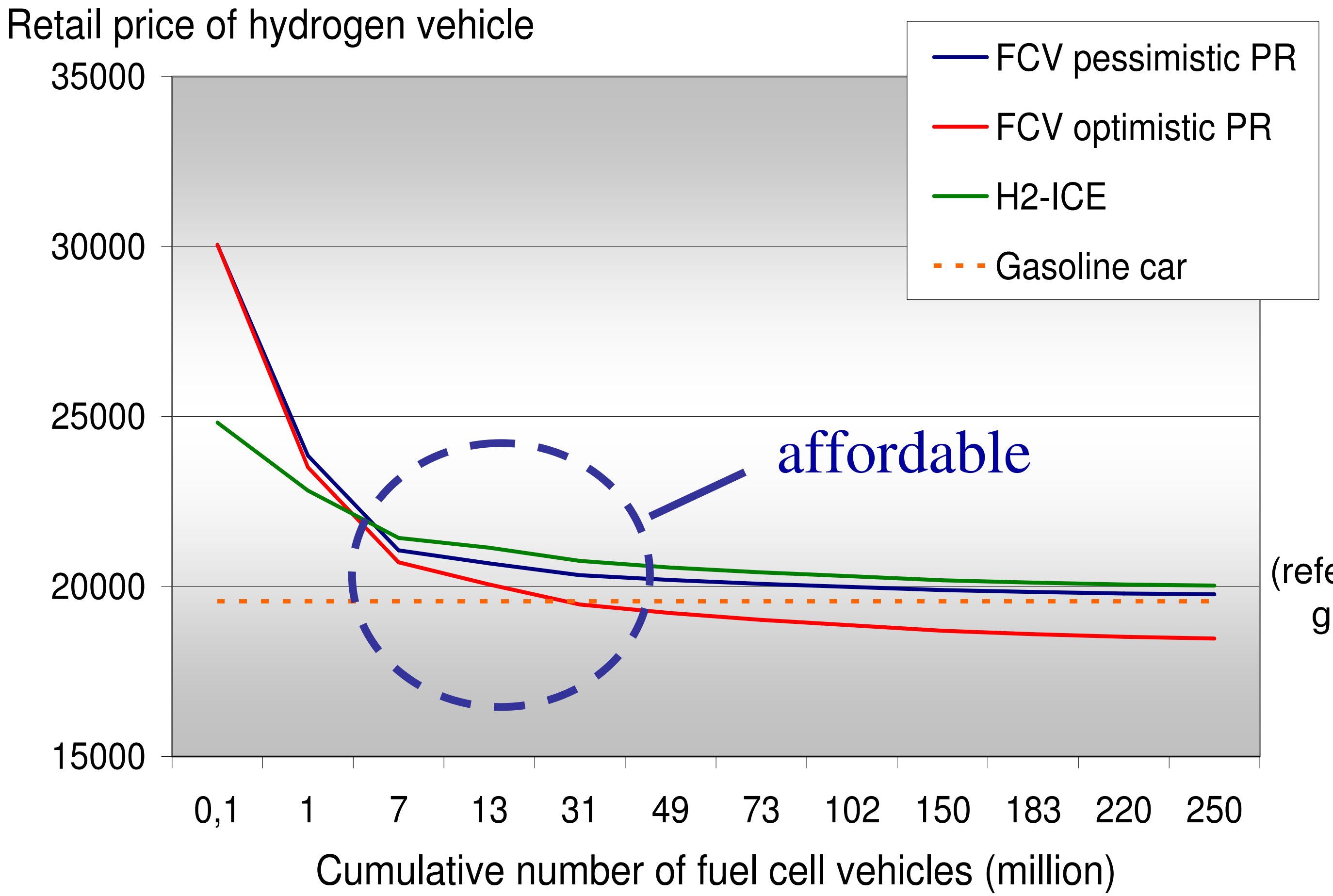
WTW fuel cost and GHG emissions, FC-Hybrid



WTW fuel cost and GHG emissions, ICE-Hybrid



HyWays – vehicle cost (medium class cars only)



(reference is 2010 gasoline car)

Energy density of storage of energy carriers

Energy Carrier	Form of Storage	Energy density weight MJ/kg	Energy density volume MJ/l
Hydrogen	Gas (1 bar)	120	0.011
	Gas (300 bar)		2.7
	Liquid (-253℃)		8.5
	Metal hydride	2	10
Natural gas	Gas (1 bar)	50	
	Liquid (-162℃)		21
Gasoline	Liquid	46	32
Diesel	Liquid	42	35
Electricity	Pb battery	0.1	0.3

Storage of hydrogen

	Liquid	Compressed 300 bar	Compressed 700 bar
On-board storage	[liter]	[liter]	[liter]
- Gasoline/Diesel	60	-	-
- Hydrogen (same drive range)	130	400	200
- Hydrogen (half drive range)	65	200	100
On-site storage [1) 2)]	[m^3]	[m^3]	[m^3]
- Gasoline/Diesel [3)]	25	-	-
- Hydrogen (truck delivery) [3)]	+ 20	+ 250 [4)]	-
- Hydrogen (on-site production)	Back-up and peak demand	+ 50 [4)]	-

[1)] Average filling station; large filling station 3 x average
[2)] 40% penetration of hydrogen cars; ~ 800 kg hydrogen/day which is 3 tube trailers/day
[3)] Storage of 2.5 times the average daily demand
[4)] ΔP of 50 bar allowed in storage

Pressure vessel with ∅ 1 m: length of 70 - 320 m
3000 kg steel per m

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The hydrogen infrastructure dilemma

- 13,350 million liter of **Fuel** (petrol, diesel and LPG) or **450 PJ** per year in the Netherlands
- 40% penetration of hydrogen cars: ~**100 PJ hydrogen** requiring ~**150 PJ Natural Gas or Electricity**
- For comparison, the annual Dutch **Natural Gas** use is **1040 PJ** and the **Electricity** use is **330 PJ** (excluding the energy sector)

- On-site production: extension current infrastructure and storage
- Compressed gas by truck: on-site storage and number of trucks
- Liquid hydrogen is energy intensive (liquefaction 30% H_2 energy content)
- Hydrogen pipeline infrastructure investments only at large demand

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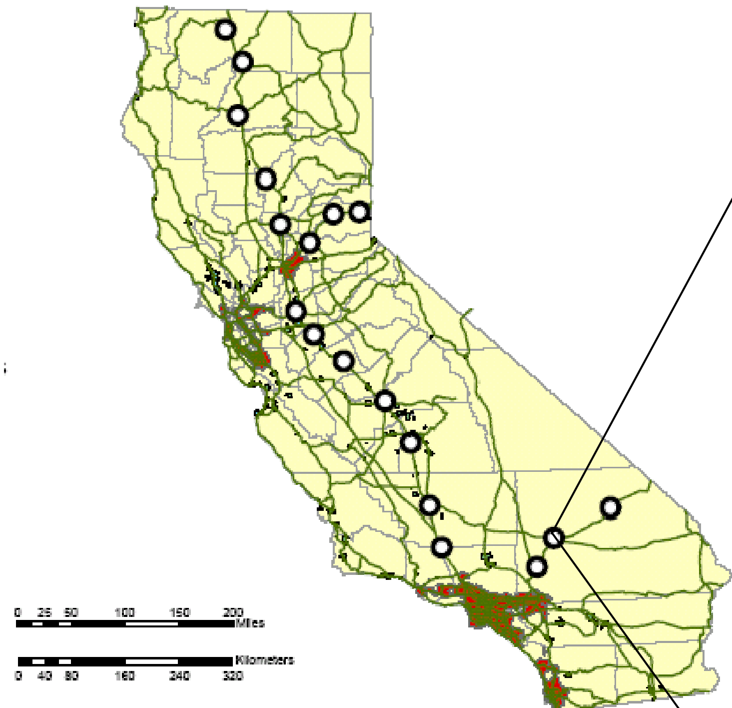
Status hydrogen and fuel cells (early 2006)

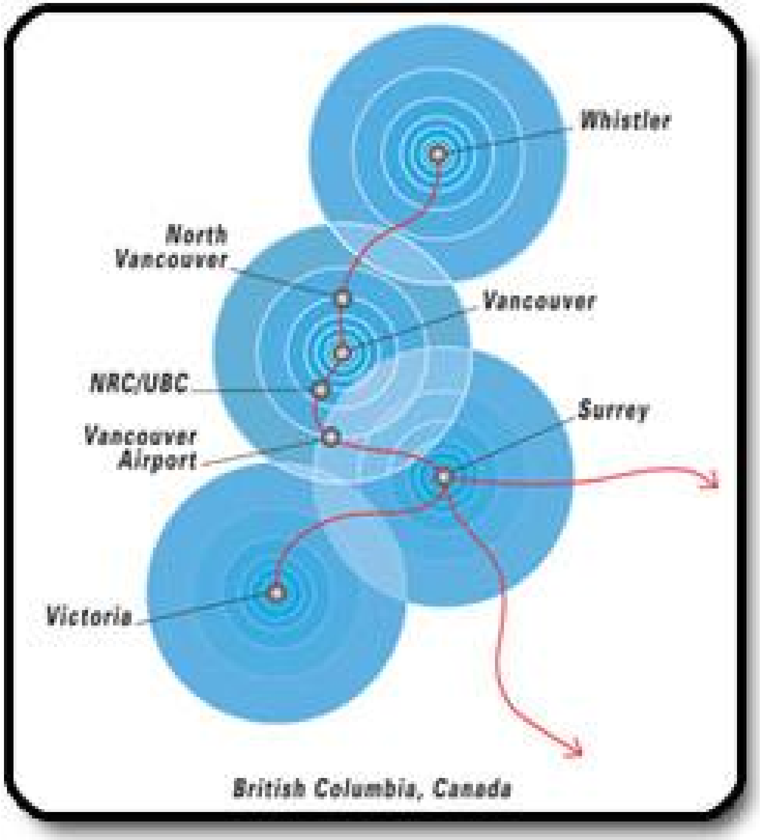
- **Currently about 400 demo projects worldwide**
- **About 100 (prototypes of) hydrogen busses**
- **About 600 (prototypes of) hydrogen passenger cars**
  (yearly production ~50 miljoen cars)
- **140 - >200 hydrogen filling stations realised/planned**
  (currently about 100 in operation)
- **About 700 pieces of "niche" transport systems**
  (APU's, Scooters, forklifts, wheel chairs, small utility vehicles, …)
- **>3000 kleinschalige stationaire systemen (<10 kW_e)**
  (ca. 75% PEMFC, rest mostly SOFC)
- **Almost 800 large-scale stationary systems (>10 kW_e)**
  (mostly in US; PAFC, MCFC and SOFC on natural gas, biogas and coal gas)
- **Interest and development becomes world wide**

Hydrogen highway in California



CALIFORNIA
HYDROGEN
HIGHWAY
NETWORK

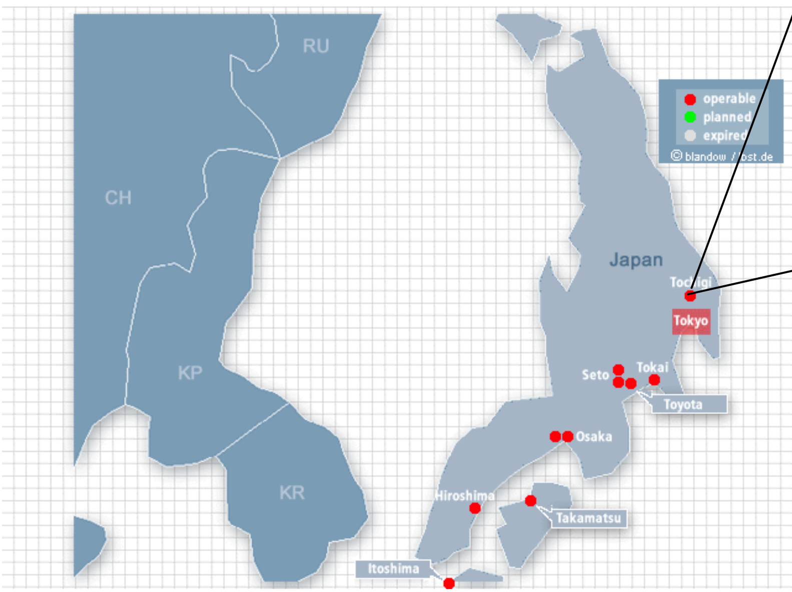
Hydrogen Highway in British Colombia, Canada

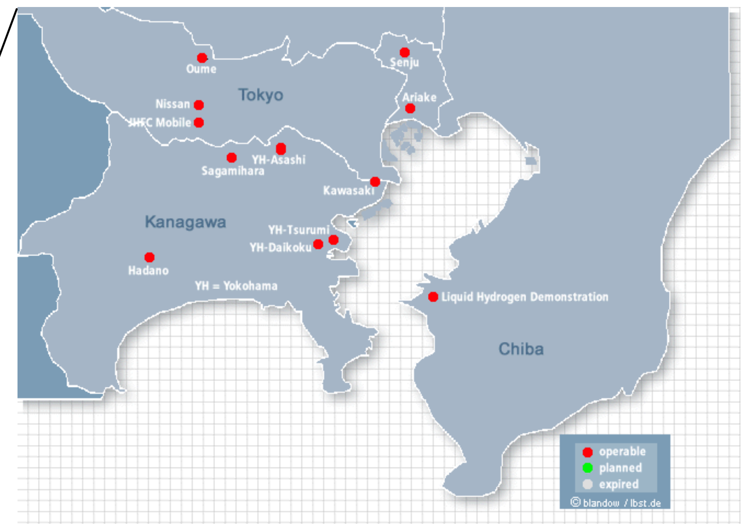


Hydrogen filling stations and cars in Japan

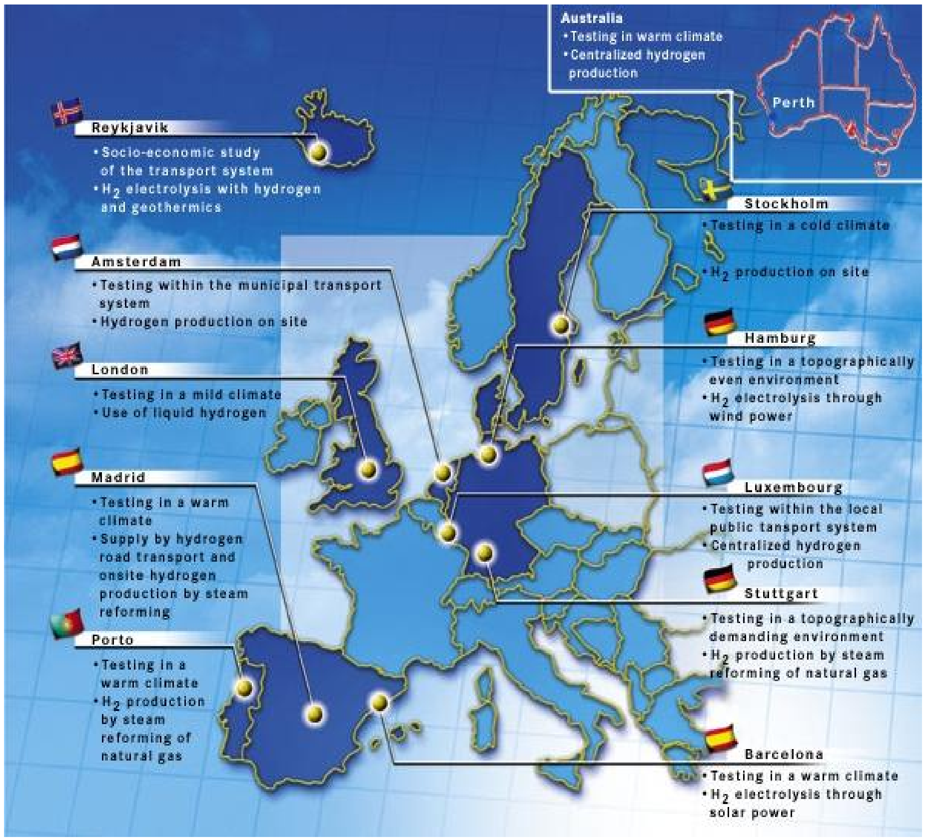
21 filling stations, 11 in Tokyo

60 fuel cell cars in operation





Europe: CUTE project



- 30 busses in 10 cities
- Different climatic conditions
- Different options H_2 production

- Availability busses the same or even better than diesel busses!

- Follow-up HyFLEET-CUTE: o.a. 14 H_2-ICE busses in Berlin

Clean Energy Partnership in Berlin








Hydrogen highway in Germany

Linde, 2005

Hydrogen highway in Noorwegen

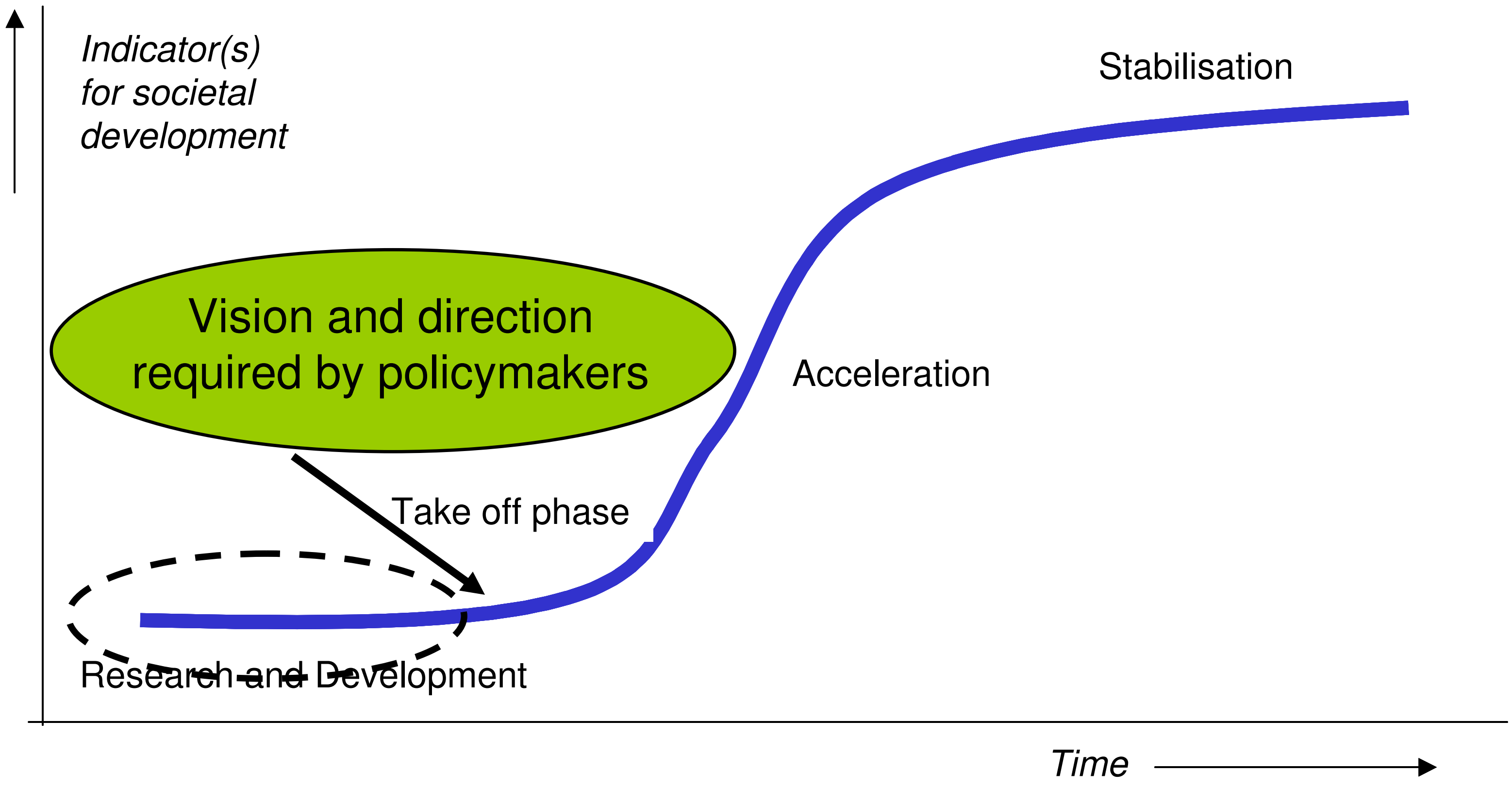
HyNor (www.hynor.no):

- 2005 – 2008
- 580 km of hydrogen highway
- Busses, taxi's, "private" cars
  (15 Toyota Prius Hybrides on H_2)
- Urban, regional and national

Investments 115 M€ in 10 jaar

Nordic countries are pro-active: Also many initiatives in Denmark and Iceland

Where are we in the transition?



Still R&D and demo-project policy. No real deployment policy yet.

Summary / Conclusions

- Hydrogen has the required characteristics for an energy carrier in a sustainable energy system
- Clear role for hydrogen in transport applications
- Stationary hydrogen only under specific conditions
- Long term outlook hydrogen fuel cost and hydrogen vehicle cost are OK, as for WTW GHG-emissions and primary energy use
- But, short term benefits w.r.t. GHG's and energy may be limited
- Hydrogen still in R&D phase: start introduction 2015-2020
- Research needed into infrastructure dilemma
- No sign of real deployment policies yet
- Large short term investments needed for (uncertain) long term benefits

Business as usual

Action

Illustration: Scientific American

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Thank you for your attention

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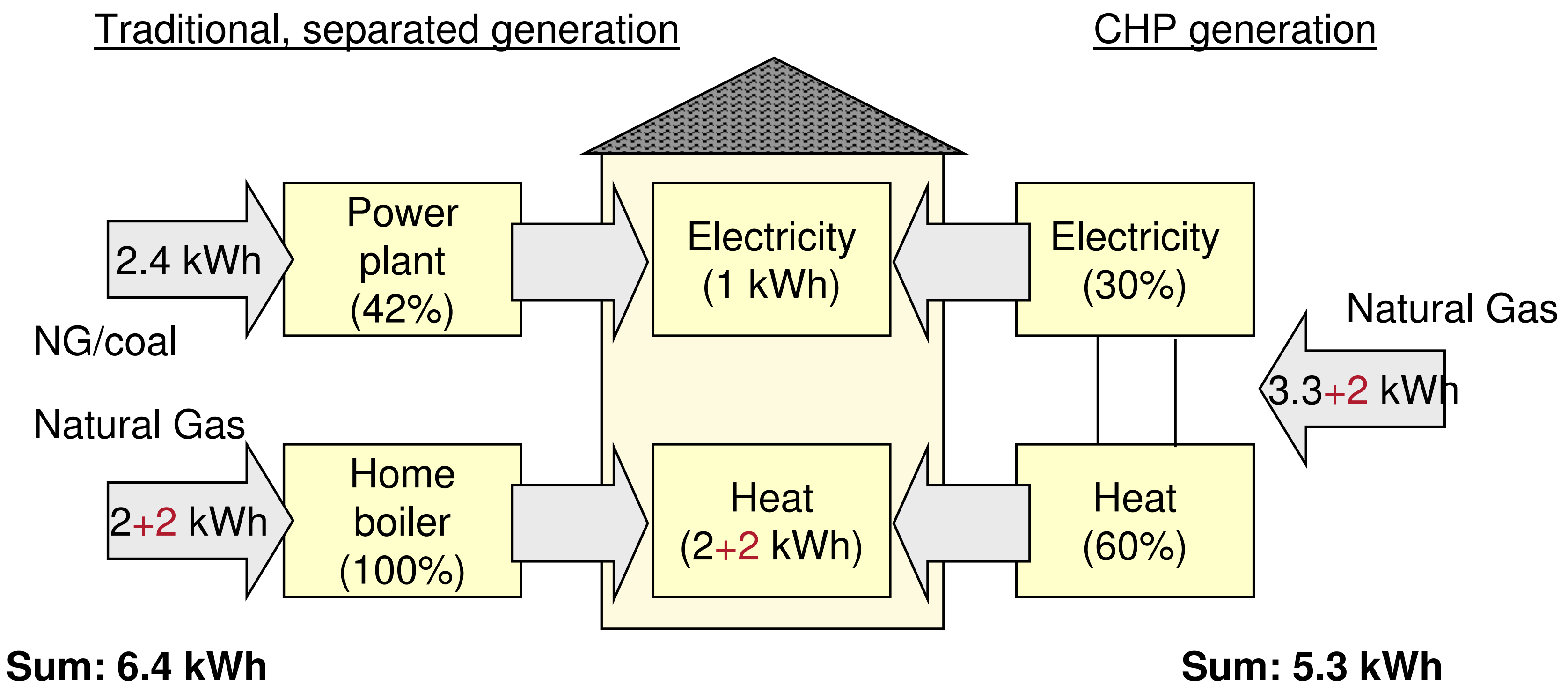
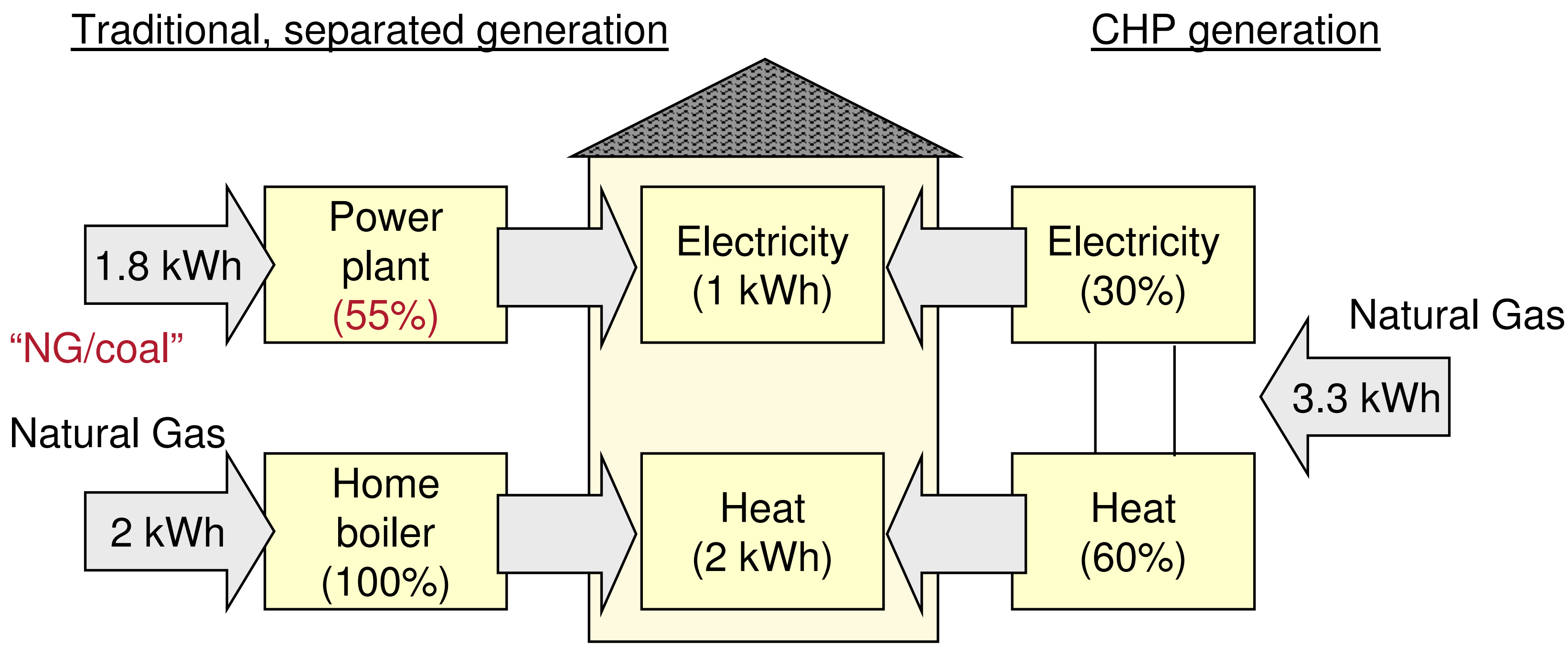
Energy saving by CHP: NG fueled, mismatch H/P ratio



$$\text{energy savings} = \frac{(6.4-5.3)}{6.4} x100\% = 17\%$$

Energy saving by CHP: NG fueled, optimisation reference



Sum: 3.8 kWh

Sum: 3.3 kWh

$$\text{energy savings} = \frac{(3.8 - 3.3)}{3.8} x100\% = 13\%$$